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NMSU CHME 491 – Introduction to Nuclear Criticality Safety

Weeks 10 - 15 Course Material

Week 10 – Criticality Safety Evaluation Documents

A crash course in Criticality Safety Evaluation Documentation – Intro & Process Description

Learning objectives

After this week, you will be able to:

1. **Describe key personnel needed to assist in preparation of criticality safety evaluations (CSEs)**

2. **Define what is required for a process description in a CSE**

CSE – Who?

- Key Players:
  - **Primary Criticality Safety Analyst:** Assists the ORS perform a CSE;
  - **Independent Reviewer Criticality Safety Analyst:** Performs a review of the technical content of the CSE
  - **Operations Responsible Supervisor (ORS):** Leads the CSE team in performing CSEs and implements the criticality safety requirements (limits) derived in the CSE prior to performing work
  - **Operators, CSOs, Process Engineers, etc.:** Provide input to the process and normal and credible abnormal conditions.


It takes teamwork to evaluate a process

CSE – What?

Where the rubber meets the road
YOU ARE HERE

- Developing a Criticality Safety Evaluation Document, *where the rubber meets the road*

- Consists of:
  - **Process Description:** describes the nature of the operations being performed and defines the boundaries of the process in a general (macro) sense. Forms the basis for the upset determination and subsequent analysis
  - **Normal/Upset Identification:** Define the normal range of processing conditions. Identify all credible abnormal conditions.
  - **Process Analysis:** Analyze the normal and credible abnormal conditions.
  - **Controls:** Recommend controls (limits) to ensure the operation remains subcritical through all normal and credible abnormal conditions.

Process Description
•Upsets

Explicit ORS Endorsement

Controls
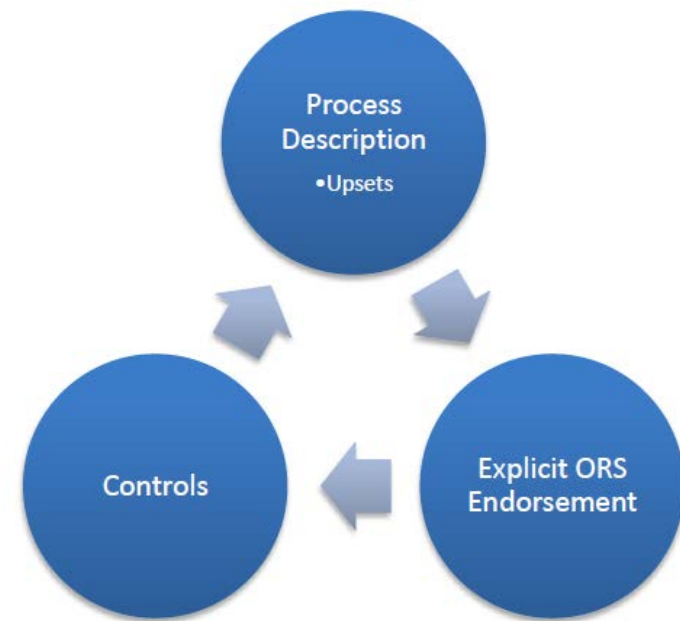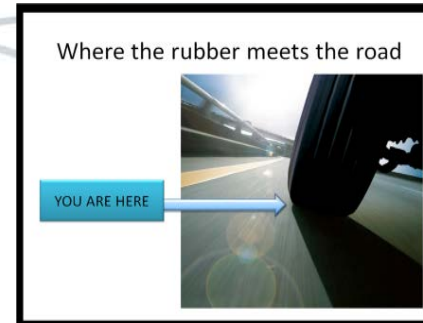
Iterative Nature of the CSE Process

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CSE – Why?

- ANS-8.1 tells us so!   →

- We're required to by law………. 10 CFR 830 → DOE O 420.1c → SD 130 → [facility-specific criticality safety program document]

- Also, we want our colleagues, friends and family to go home safe at the end of the day

ANS-8.1, Section 4.1.2 Process Analysis Requirement:

Before a new operation with fissionable material is begun, or before an existing operation is changed, it shall be determined that the entire process will be subcritical under both normal and credible abnormal conditions.

CSED – Process Description

- **NCS-AP-004 tells us what to include**

- **DOE-STD-3007-2007 outlines requirements/found in Example of Process Descriptions**
  - Standard Criticality Safety Requirements (SCSR) PD (somewhat generic)
  - Level 1 CSE implementing SCSR CSE (more specific)

CSE Development Process (1)

Operations (Ops) establishes a need

- New operation required OR changes to an already established operation

- **For new (not yet installed) operations, it is preferable to NCS to get involved at the design phase, this way the process may be inherently 'safe by design' by incorporating passive engineered features, i.e. geometrically favorable equipment (tanks), adequate spacing between process tanks, etc.**

  - Could result in less reliance on administrative controls (controls operators need to implement/keep in mind while performing the operation)

  - Could also lead to higher mass limits => more efficient throughput, etc.

    - In a way, NCS Engineers also act as industrial engineers, ensuring a safe and efficient process

CSE Development Process (2)

Assemble the team!

- ➤ Operations Responsible Supervisor (ORS)* – leads CSE team
  - ➤ Operations Responsible Manager (ORM)* – signs for concurrence
- ➤ CSA (primary)* – writes the evaluation, provides technical guidance, performs the analysis
- ➤ Criticality Safety Officer (CSO)* – Ops/NCS interface
- ➤ CSA Independent Reviewer (CSA-IR)* – technical editor for the CSE; joins the team once all normal and credible abnormal conditions are defined (thru Section 4 of CSE complete)
- ➤ Subject Matter Experts (SMEs) – usually Process Engineers (PrEs), but can also include Fire Protection, Seismic experts, etc.
- ➤ Operators – provide experience input; concur with controls
- ➤ NCS Manager* – provides a final 'consistency check' on CSEs

- **See NCS-AP-004, Section 2. for specific roles and responsibilities**
- **For this course, your role is the CSA**
- ***These players sign the CSE once complete**

CSED Development Process (3)

Walk down the Operation

- **Allows the CSA to get a feel for the operating environment**

- **View the glovebox (GB)/location layout**
  - Nearby fissionable material operations (FMOs)?

- **Note ancillary systems connected to the GB – e.g. water lines, gas lines, chemicals plumbed to the GB, etc.**

- **Lab room attributes – is there an overhead fire suppression system (FSS)?**

- **Discuss/observe material flow – intro and exit**

- **Observe equipment in the GB – are there items that provide Reflection/Moderation potential? Geometry/Volume issues?**

- **Mentally begin the Hazards Analysis (HA) process…**

- **See NCS-AP-004, R0 Appendix B for evaluation walkdown question examples**

- **Since you will not be able to physically walkdown the operation you will be evaluating, this information will be provided for you**

  - If you need more information, ask!

- **The HA process will be discussed in next week's lecture, but as the CSED development process is iterative, it's important to keep in mind as your write your process description**

CSED Development Process (4)

You will write the Process Description (PD)

- **Include:**
  - Physical location description
    - Does the process you're evaluating reside in a GB, on the floor (floor staging), in a safe, etc.?
    - What else is nearby?
  - Equipment in GB
  - Material forms: Feed, Product, any non-fissionable material used
    - Are there form changes? i.e. metal -> oxide,
  - Description of the actual process, e.g. splitting, dissolving, 'burning', oxidizing, etc.

- **ORS (+SME + Operators) provide input**
  - per NCS-AP-004, the ORS concurs with PD prior to identification of normal and credible abnormal conditions

- **See Criticality Safety Evaluation Document Template**

- **Remember, a picture is worth a thousand words! Don't hesitate to request equipment drawings/specs and include them in your CSED**

Example Process Description

- **See example in files**

Week 10 Reading and assignments

- Study the slides

- Read NCS-AP-004 and review DOE-STD-2007
  - Sections outlined in study sheet

- **For this week's discussion, write the Process Description (PD) for your CSED and post it**

- **Peer review 2 other PDs and provide comments/feedback**

Due Dates:

Discussion   Friday, 11:59 PM

Disc. Peer Review   Sunday, 11:59 PM

Supplemental Resources

- NCS-AP-004, *Criticality Safety Evaluations* (formerly NCS-GUIDE-01, R2)

- DOE-STD-3007-2007, *Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities*

- SCSR CSED

- Example application of SCSR CSED

Week 11 – Criticality Safety Evaluation Documents

A crash course in Criticality Safety Evaluation Documentation – Hazard Analysis

Learning objectives

After this week, you will be able to:

1. **Identify and discuss the methods used to determine and analyze failure modes**

CSED - Recap

- Last week you wrote the Process Description for you CSED
  - Ensure you incorporate comments from your peer reviews and your LANL contact

CSED - Hazard Analysis (HA) Process (1)

Assemble the team! (again!)

- ➢ ORS
- ➢ CSA
- ➢ Operators – key players
- ➢ CSO
- ➢ SMEs (PrEs)

Choose HA method:

- ■ "What-If" method
- ■ Hazard and Operability Analysis
- ■ Quantitative Event or Fault Trees
- ■ Failure Modes and Effects Analysis

- • **For definition of roles, see Week 10 slides**
- • **See the Hazard Analysis Help folder for more information on specific HA methods**

CSED - HA Process (2)

- Establish the normal operating conditions
  - Expected mass, reflector/moderation conditions, etc.
    - Remember MAGIC MERV
  - Expected form changes (if any, i.e. converting a metal to an oxide)

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CSED - HA Process (3)

- **Discuss what could go wrong**
  - This is where the Operator's experience is key! They typically know what goes wrong and at what frequency
- **Identify which parameter that upset affects**
  - Remember MAGIC MERV (again)
- **Is the upset expected, unlikely, or not credible?**
- **Examples:**
  - A container is introduced – possible Mass/Interaction upset
  - A cooling line breaks/valve leaks – water ingress = Moderation/Reflection upset

- **May help to outline this information in a table**
  - See slide tbd for example

- **DOE-STD-3007-2007 defines an unlikely event as an event that is not expected to occur more than once in the lifetime of a facility**
- **NCS-AP-004, R1 defines an unlikely event as improbable but credible; cannot be ignored**

CSED - HA Process (4)

- **Ops likes to think in 'success space' –** *My operation runs smoothly… That's never happened in my operation…*

- **… Or forgets we're all human:** *My operators don't make mistakes…*
  - *Spoiler alert – we ALL make mistakes, ~12 mistakes per day on average according to research…*

- **CSA's job is to remain objective and objective – ask questions!**

… except in operations with fissionable material, where a mistake can lead to a *criticality [not happy]* accident…
We write evaluations to account for 'mistakes' and ensure credible mistakes are still subcritical!

CSED - HA Process (4)

MAJOR HINT:

- **The hazard analysis stems from a well-defined Process Description (PD)**

  - All normal and credible abnormal conditions cannot be identified from a process condition that hasn't been described in the PD

    => PD informs HA <=

- **DOE Order 420.1c establishes the requirement for analysis of Design Basis Events (DBE), e.g. an earthquake or fire**

  - In other words, we are required to ensure conditions arising from a DBE remain subcritical

It's critical to write the Process Description well enough to identify what is normal and what could go wrong (identify normal and credible abnormal conditions) in a fissionable material operation (FMO).

CSED HA (5)

Choose an HA method

Write the Hazard Analysis (HA) for your assigned operation in the format described in NCS-AP-004

- **Include:**
  - Description of the upset
  - What makes the upset unlikely OR not credible
    - E.g. - use of Detailed Operating Procedures (DOPs), NMCA system, operator training.
- **ORS (+SME + Operators) provide input**
- **Work with your LANL NCS point of contact for more information**

- **See NCS-AP-004, R0 Appendix A – Criticality Safety Evaluation Document Template**
- **Use example CSED for language**

Example Hazard Analysis Write-up

- **See example in files**

Week 11 Reading and assignments

- Study the slides

- Review NCS-AP-004 and DOE-STD-2007

- **For this week's discussion, write the Hazard Analysis (HA) for your CSED and post it**

- **Peer review 2 other HAs and provide comments/feedback**

Due Dates:

| Discussion | Friday, 11:59 PM |
| Disc. Peer Review | Sunday, 11:59 PM |

Supplemental Resources

- NCS-AP-004, *Criticality Safety Evaluations* (formerly NCS-GUIDE-01, R2)

- NCS-GUIDE-02, *Hazard Analysis for the Identification of Process Conditions*

- Guidelines for Hazard Evaluation Procedures, 3rd edition, Center for Chemical Process Safety, New York, 2008 *(bonus points if you can find this book in the Shires Reading Room & post a picture)*

- DOE-STD-3007-2007, *Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities*

- SCSR CSED

- Example application of SCSR CSED

- Hazard Analysis Help folder on Canvas

- DOE NCSP Nuclear Criticality Safety Engineer Training: https://ncsp.llnl.gov/trainingMain.html

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Week 12 – Criticality Safety Evaluation Documents

A crash course in Criticality Safety Evaluation Documentation – Analysis

Learning objectives

After this week, you will be able to:

- **Describe how subcritical margins and limits are determined**

CSED - Analysis Process (1)

Where the CSA puts their skills to work!

Perform analysis of normal and credible abnormal process conditions

- Last week you identified the normal and credible abnormal process conditions for your operation

- This week you will learn how to show those operations are subcritical, then do it yourself for your operation

CSED - Analysis Process (2)

- Establish the normal operating conditions to be subcritical

- All must be shown to be subcritical:
  - Expected mass, reflector/moderation conditions, etc.
  - Expected form changes (if any, i.e. converting a metal to an oxide)

CSED - Analysis Process (3)

- Establish the credible abnormal conditions to be subcritical

- All must be shown to be subcritical:

  - Any overmass conditions, credible additional reflector conditions, abnormal moderation conditions (i.e. water intrusion into the glovebox), etc.

  - Credible though unlikely form changes (if any, i.e. metal oxidizing in a non-inert glovebox)

Recall from Week 3 what is subcritical...

- If the number of fissions occurring per second

  - Are *decreasing*: the system is subcritical

  - Are *constant*: the system is critical

  - Are *increasing*: the system is supercritical

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Also recall… Parameters of Importance

- Parameters that affect k_{eff} are:
  - **M**ass
  - **A**bsorption
  - **G**eometry/Shape
  - **I**nteraction
  - **C**oncentration/Density
  - **M**oderation
  - **E**nrichment
  - **R**eflection
  - **V**olume

- Parameters are somewhat interdependent
  - Changing one often changes others

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CSED - Analysis Process (4)

Subcritical values for criticality safety evaluations are determined by one of the following four methods, in order of preference:

1. By reference to experiments and/or widely accepted handbooks/guides of critical data with appropriate adjustments to ensure subcriticality when uncertainties in the parameters reported in the experiment documentation/handbooks/guides are considered.

- **Examples of handbooks/guides:**
  - Internal Criticality Safety Benchmark Evaluation Project (ICSBEP)
  - LA-10860-MS

CSED - Analysis Process (5)

Subcritical values for criticality safety evaluations are determined by one of the following four methods, in order of preference:

2. By reference to national standards that present subcritical limits, with due regard for conditions of applicability.

- **Examples:**
  - Single parameter subcritical limits summarized in Table 1 and 3 of ANSI/ANS-8.1
    - Use of these subcritical limits requires no additional adjustment to ensure subcriticality

CSED - Analysis Process (6)

Subcritical values for criticality safety evaluations are determined by one of the following four methods, in order of preference:

3. By reference to widely accepted handbooks/guides of subcritical limits

- Examples:
  - LA-12808
  - TID-7016
    - Use of these subcritical limits requires no additional parameter adjustments to ensure subcriticality

CSED - Analysis Process (7)

Subcritical values for criticality safety evaluations are determined by one of the following four methods, in order of preference:

4. By validated calculation methods

4.1 Hand Calculations

Industry standard hand calculation techniques documented in widely accepted handbooks/guides are considered validated and do not require a written validation report as long as the conditions under which the method was developed are applicable for the situation under analysis.

- **Calculation Technique Examples:**

  - Limiting Surface Density
  - Buckling
  - Density Analog

- **Handbook/Guide Examples:**

  - LA-10860
  - TID-7016
  - TID-7028
  - LA-12808
  - LA-14244.M

CSED - Analysis Process (8)

Subcritical values for criticality safety evaluations are determined by one of the following four methods, in order of preference:

4. By validated calculation methods

4.2 Computer based methods

- **Stay tuned for more detail in next week's lecture!**

For your CSED…

- **Don't sweat it! We won't ask you to run calculations for this class**

- **You will take your operation, write your process description, identify the normal and credible abnormal condition, then apply the Standard Criticality Safety Requirements (SCSR) CSED**

  - The calculations have already been completed for the SCSR, you need only verify your operation does not introduce any upset conditions not covered by the SCSR

Week 12 Reading and assignments

- Study the slides

- Review NCS-AP-004 and DOE-STD-2007

- For this week's discussion, write out the analysis section for your CSED and post it

- Peer review 2 other analyses and provide comments/feedback

Due Dates:

Discussion	Friday, 11:59 PM
Disc. Peer Review	Sunday, 11:59 PM

Supplemental Resources

- NCS-AP-004, *Criticality Safety Evaluations* (formerly NCS-GUIDE-01, R2)

- NCS-GUIDE-02, *Hazard Analysis for the Identification of Process Conditions*

- DOE-STD-3007-2007, *Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities*

- SCSR CSED

- Example application of SCSR CSED

Week 13 – Criticality Safety Evaluation Documents

A introduction to Calculations for CSEDs

Learning objectives

After this week, you will be able to:

- **Describe the importance of validation of computer codes and how it is accomplished.**
- **Develop contingency analysis, limits and controls**

CSED – Recap – keep in mind the goals of analysis…

- **Establish the normal operating conditions to be subcritical**

- **All must be shown to be subcritical:**
  - Expected mass, reflector/moderation conditions, etc.
  - Expected form changes (if any, i.e. converting a metal to an oxide)

CSED - … and upset conditions

- **Establish the credible abnormal conditions to be subcritical**

- **All must be shown to be subcritical:**
  - Any overmass conditions, credible additional reflector conditions, abnormal moderation conditions (i.e. water intrusion into the glovebox), etc.
  - Credible though unlikely form changes (if any, i.e. metal oxidizing in a non-inert glovebox)

CSED – More on calculation methods:

Subcritical values for criticality safety evaluations are determined by one of the following four methods, in order of preference:

4. By validated calculation methods

4.2 Computer based methods

- **Ensure the hardware/software combination utilized has been validated and verified in accordance with ANSI/ANS-8.24**

- **Ensure the computational model being analyzed resides within the defined area of applicability**

- **Computer based methods:**
  - Monte Carlo based methods:
    - MCNP
    - SCALE
    - COG

- **The upper subcritical limit (USL) is defined as:**
  - USL = 1.0 + (bias) – (bias uncertainty) – (margin of subcriticality)
  - A calculation is <u>subcritical</u> if
    - k_{eff} < USL

CSED – Computer based methods (cont.)

- **The Margin of Subcriticality (MoS) should be selected to ensure that calculated conditions will actually be subcritical**

  - Should take into account the sensitivity of the system or process variations in fissile form, geometry, or other physical characteristics.

- **The MoS shall be no less than 0.02:**

  - A margin of 0.005 for nuclear data uncertainty

  - 0.005 for potential undiscovered errors in the computation software

  - An additional 0.01 for conservatism

- **Computer based methods:**

  - MCNP

  - SCALE

  - COG

- **The upper subcritical limit (USL) is defined as:**

  - USL = 1.0 + (bias) – (bias uncertainty) – (margin of subcriticality (MoS))

CSED – Computer based methods (cont.)

- **The primary CSA shall determine that the calculation model(s) fit within the area of applicability (AoA) of the benchmark critical experiments used for code validation.**

  - The AoA determination quantifies parameters potentially important to the computational calculation of k_{eff}

  - This comparison of calculation models and the benchmark critical experiments ensures that the selected USL is valid for the calculations being performed.

  - For systems which are outside the validation area of applicability, an area of applicability margin (AoA) may also be warranted, depending on the specific problem being analyzed.

- The analyst must document and justify any extrapolation beyond the validation area of applicability, including any chosen margin.

- **The resulting USL with an AoA margin is define as:**

  - USL = 1.0 + (bias) – (bias uncertainty) – (MoS) – (AoA margin)

  - A calculation is subcritical if:

    $$k_{eff} < USL$$

CSED – Computer based methods (cont.)

- **The primary CSA shall ensure validation requirements for the kcode (number of particles per cycle, minimum active cycles, et cetera) are met.**

- **The primary CSA shall also ensure the convergence via Shannon Entropy or other method of computational results.**

For your CSED…

- Again, not necessary to run calculations for this class

- For your operation, you've written your process description, identified the normal and credible abnormal condition, then applied the Standard Criticality Safety Requirements (SCSR) CSED
  - The calculations have already been completed for the SCSR, you need only verify your operation does not introduce any upset conditions not covered by the SCSR

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For your CSED…

- Finally, ensure limits derived from the SCSR CSED are applicable to your process

- The application CSED may further *restrict* the operation by conservatively increasing the requirement set (e.g. removing allowed forms that are not processed at the specific operation location).

- An SCSR Application CSED shall not be used to allow a *less restrictive* control set.
  - This may only be done via complete, stand alone criticality safety evaluation

Week 13 Reading and assignments

- Study the slides

- Review NCS-AP-004 and DOE-STD-2007 as needed

- For this week's discussion, post the 'final version' of your CSED

- Peer review 2 other analyses and provide comments/feedback

- Your contact at LANL will work with you until the end of the semester to edit your CSED for implementation at LANL

- Final CSEDs due week of November 27th

Due Dates:

| Discussion | Friday, 11:59 PM |
| Disc. Peer Review | Sunday, 11:59 PM |

Supplemental Resources

- NCS-AP-004, *Criticality Safety Evaluations* (formerly NCS-GUIDE-01, R2)

- NCS-GUIDE-02, *Hazard Analysis for the Identification of Process Conditions*

- DOE-STD-3007-2007, *Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities*

- SCSR CSED

- Example application of SCSR CSED

Week 14 – Thanksgiving Break

Week 15 – Nuclear Criticality Safety at LANL

A Day in Criticality Safety at LANL

Crit Safety Operations at LANL

- Familiarization with Different Facilities & Operations
- Reviewing Fissile Material Operations
- Writing a CSED
- Performing Calculations
- Providing Technical Guidance
- Emergency Preparedness

Facilities

- PF-4 – Plutonium-Processing Facility
- LANSCE – Los Alamos Neutron Science Center
- STO – Science and Technology Operations
- NNSS – Nevada Nuclear Security Site
- CMR – Chemistry and Metallurgy Research Facility
- RLUOB – Radiological Laboratory Utility Office Building

PF-4

- Only Fully Operational, Full Capacity Plutonium Facility
- Stockpile Stewardship
- Plutonium Processing
- Nuclear Materials Stabilization
- Materials Disposition
- Nuclear Forensics
- Nuclear Counter-Terrorism

PF-4 Cont.

- Plutonium-238 Research for Space Applications
- Minor Actinide Chemistry Research
- Destructive and Non-Destructive Analysis
- Plutonium Pit Manufacturing and Surveillance

LANSCE

- Nations Most Powerful Linear Accelerator
- Lujan Center
  - Basic and Applied Neutron Science
- Proton Radiography
- Isotope Production
- Ultra Cold Neutrons

STO

- NISC – Nonproliferation and International Security Center
- Sigma – Materials Manufacturing
- BTF – Beryllium Technology Facility

NNSS

- Experimental Support of Stockpile Stewardship
- Nuclear Nonproliferation and counter-proliferation
- Nuclear and Radiological Emergency Response
- Radiological Environmental Monitoring and Protection
- Subcritical Test Site

The Nevada National Security Site
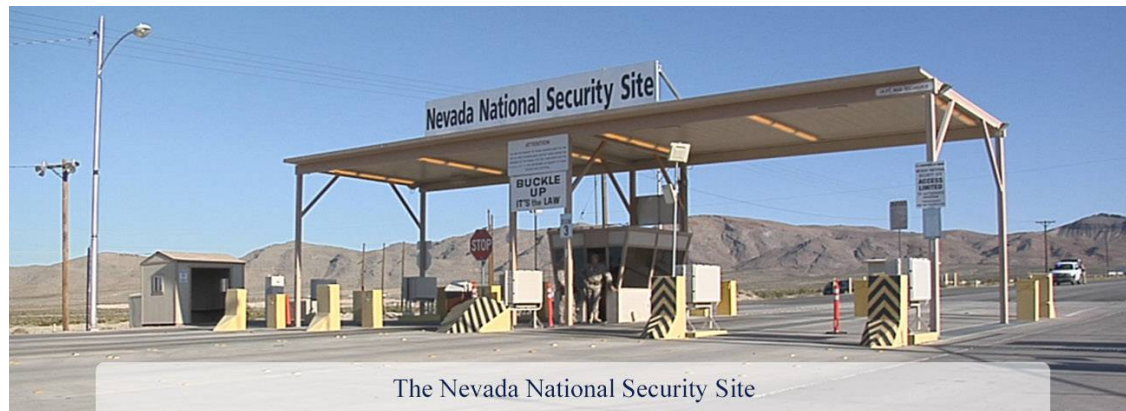
CMR

- Plutonium and Uranium Research
- Analytical Chemistry
- Uranium Processing
- Minor Actinide Research
- Metallography

RLUOB

- Replacement of CMR

- Fully Functional Analytical Chemistry and Materials Characterization

- Office Support Housing
    - MET – Manufacturing Engineering and Technologies

- Home to Crit. Safety Division!!!

Other Experiences

- Numerous Facility Tours
  - MET 2
  - TA – 18
  - High Performance Computing (HPC)
- Training Opportunities
  - UNM Courses
  - Hand-On Training
- Conferences

- http://www.lanl.gov/about/_assets/docs/fact-sheets/TA55.pdf

- http://www.lanl.gov/about/_assets/docs/fact-sheets/CMR.pdf

- http://lansce.lanl.gov/

- http://www.lanl.gov/about/_assets/docs/fact-sheets/rluob.pdf

Career Opportunities in Crit Safety

Crit Safety at LANL

- Division of 24
  - 7 Qualified Analysts
  - 13 Analysts in Training
  - 4 Sub-Contractors
- 30 Analysts Requested by DOE
- 5 New Hires this Year

The Division

- Monthly Socials

- Quarterly Picnics

- Qualification Bonus Incentives

- Social Networking Groups

- University Campus Feel

Opportunities at LANL

- Opportunity to Move Around
- Qualified Analyst Expertise are Valued
- Become a Criticality Safety Officer (CSO)
  - Operations side of Crit Safety
- Nuclear Engineering and Nonproliferation Division (NEN)
  - Safeguards
  - Advanced Nuclear Technology
  - Critical Experiments

Outside Opportunities

Idaho National Lab

- Idaho Falls, Idaho
- Reactor Research
  - Next Generation
  - Fuel Cycle R&D
- Naval Ties
- Nonproliferation

Sandia National Lab

- Albuquerque, New Mexico
- Arms Control and Nonproliferation
- Decommissioning
- Reactor Research
- Fusion & Pulse Power

Lawrence Livermore National Lab

- Livermore, California (Bay Area)
- Plutonium Research Lab
- Nonproliferation and Security

Oak Ridge National Lab/Y-12

- Oak Ridge, Tennessee
- Uranium Research
- Uranium Production & Thermonuclear Devices
- Enrichment Facilities
- Stockpile Stewardship
- Naval Reactors

THE Y-12 NATIONAL SECURITY COMPLEX
70 YEARS OF MAKING THE WORLD SAFER

Commercial Facilities

- Fuel Fabrication:
    - Nuclear Fuel Services – Erwin, Tennessee
    - BWXT Nuclear Operations Group – Lynchburg, Virginia
- Fuel Enrichment:
    - Paducah Gas Diffusion – Paducah, Kentucky
    - Portsmouth Gas Diffusion – Piketon, Ohio
    - URENCO Centrifuge – Eunice, New Mexico

Savannah River Site

- Southern South Carolina
- Radiochemical Separation
- Tritium Production
- Mixed Oxide Fuel Manufacturing
- Future Research Reactors

Hanford Decommissioning

- Hanford, Washington
- Previously Weapons Production Reactors
- High Level Waste Storage
- Large Cleanup Project
- Uncertainty of Stored Material
- Waste Treatment and
   Vitrification Plant